FORM PTO-1390 (Modified) (REV 11-2000) U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE

TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371

ATTORNEY'S DOCKET NUMBER: **29610/CDT096**

U.S APPLICATION NO. (IF KNOWN, SEE 37 CFR): **10/009079**

INTERNATIONAL APPLICATION NO.	INTERNATIONAL FILING DATE	PRIORITY DATE CLAIMED
PCT/GB00/02121	**1 June 2000**	**9 June 1999**

TITLE OF INVENTION
LIGHT-EMITTING DEVICES

APPLICANT(S) FOR DO/EO/US
Julian CARTER and Stephen K. HEEKS

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☒ This is an express request to begin national examination procedures (35 U.S.C. 371(f)). The submission must include itens (5), (6), (9) and (24) indicated below.
4. ☒ The US has been elected by the expiration of 19 months from the priority date (Article 31).
5. ☒ A copy of the International Application as filed (35 U.S.C. 371 (c) (2))
   a. ☒ is attached hereto (required only if not communicated by the International Bureau).
   b. ☒ has been communicated by the International Bureau.
   c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).
6. ☐ An English language translation of the International Application as filed (35 U.S.C. 371(c)(2)).
   a. ☐ is attached hereto.
   b. ☐ has been previously submitted under 35 U.S.C. 154(d)(4).
7. ☒ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371 (c)(3))
   a. ☐ are attached hereto (required only if not communicated by the International Bureau).
   b. ☐ have been communicated by the International Bureau.
   c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
   d. ☒ have not been made and will not be made.
8. ☐ An English language translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9. ☐ An oath or declaration of the inventor(s) (35 U.S.C. 371 (c)(4)).
10. ☐ An English language translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371 (c)(5)).
11. ☒ A copy of the International Preliminary Examination Report (PCT/IPEA/409).
12. ☒ A copy of the International Search Report (PCT/ISA/210).

Items 13 to 20 below concern document(s) or information included:

13. ☒ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
14. ☐ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
15. ☒ A **FIRST** preliminary amendment.
16. ☐ A **SECOND** or **SUBSEQUENT** preliminary amendment.
17. ☐ A substitute specification.
18. ☐ A change of power of attorney and/or address letter.
19. ☐ A computer-readable form of the sequence listing in accordance with PCT Rule 13ter.2 and 35 U.S.C. 1.821 - 1.825.
20. ☐ A second copy of the published international application under 35 U.S.C. 154(d)(4).
21. ☐ A second copy of the English language translation of the international application under 35 U.S.C. 154(d)(4).
22. ☐ Certificate of Mailing by Express Mail
23. ☒ Other items or information:

Return receipt postal card

U.S. APPLICATION NO. (IF KNOWN, SEE 37 CFR)	INTERNATIONAL APPLICATION NO	ATTORNEY'S DOCKET NUMBER
10/009079	PCT/GB00/02121	29610/CDT096

24. The following fees are submitted:.

BASIC NATIONAL FEE (37 CFR 1.492 (a) (1) - (5)) :

		CALCULATIONS PTO USE ONLY
☐	Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO	$1040.00
☒	International preliminary examination fee (37 CFR 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO	$890.00
☐	International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.445(a)(2)) paid to USPTO	$740.00
☐	International preliminary examination fee (37 CFR 1.482) paid to USPTO but all claims did not satisfy provisions of PCT Article 33(1)-(4)	$710.00
☐	International preliminary examination fee (37 CFR 1.482) paid to USPTO and all claims satisfied provisions of PCT Article 33(1)-(4)	$100.00

ENTER APPROPRIATE BASIC FEE AMOUNT =	**$890.00**	
Surcharge of **$130.00** for furnishing the oath or declaration later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492 (e)).	**$0.00**	

CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE		
Total claims	16 - 20 =	0	x $18.00	**$0.00**	
Independent claims	1 - 3 =	0	x $84.00	**$0.00**	
Multiple Dependent Claims **(check if applicable)**.			☐	**$0.00**	
TOTAL OF ABOVE CALCULATIONS =				**$890.00**	
☐ Applicant claims small entity status. See 37 CFR 1.27). The fees indicated above are reduced by 1/2.				**$0.00**	
SUBTOTAL =				**$890.00**	
Processing fee of **$130.00** for furnishing the English translation later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492 (f)). +				**$0.00**	
TOTAL NATIONAL FEE =				**$890.00**	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31) **(check if applicable).** ☐				**$0.00**	
TOTAL FEES ENCLOSED =				**$890.00**	
				Amount to be: refunded	$
				charged	$

a. ☒ A check in the amount of **$890.00** to cover the above fees is enclosed.

b. ☐ Please charge my Deposit Account No. _____ in the amount of _____ to cover the above fees. A duplicate copy of this sheet is enclosed.

c. ☒ The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. **13-2855** A duplicate copy of this sheet is enclosed.

d. ☐ Fees are to be charged to a credit card. **WARNING:** Information on this form may become public. **Credit card information should not be included on this form.** Provide credit card information and authorization on PTO-2038.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO:

James P. Zeller
Marshall, Gerstein & Borun
233 S. Wacker Drive
6300 Sears Tower
Chicago, IL 60606
(312) 474-6300

SIGNATURE

James P. Zeller
NAME

28,491
REGISTRATION NUMBER

December 3, 2001
DATE

PATENT APPLICATION

IN THE UNITED STATES PATENT
AND TRADEMARK OFFICE

Applicants: Carter et al.	"EXPRESS MAIL" mailing label No. EL564464875US.
Serial No.: To be assigned	Date of Deposit: December 3, 2001
Filed: Herewith (December 3, 2001)	I hereby certify that this paper (or fee) is being deposited with the United States Postal Service "EXPRESS MAIL POST OFFICE TO ADDRESSEE" service under 37 CFR §1.10 on the date indicated above and is addressed to: Commissioner for Patents, Box PCT, Washington, D.C. 20231
For: LIGHT-EMITTING DEVICES	
Group Art Unit: To be assigned	
Examiner: To be assigned	Richard Zimmermann

PRELIMINARY AMENDMENT

Commissioner for Patents
Box PCT
Washington, DC 20231

Sir:

Please amend this application as follows.

IN THE SPECIFICATION:

Page 1 immediately following the title, please insert the following:

--This is the U.S. national phase of International Application No. PCT/GB00/02121 filed June 1, 2000, the entire disclosure of which is incorporated herein by reference.--

IN THE ABSTRACT:

Please add an abstract as set forth on the attached sheet.

IN THE CLAIMS:

Please amend claims 1, 3-14, and 16 as follows:

1. (Amended) An electroluminescent device comprising:

a first electrode;

a second electrode; and

a light-emissive region of electroluminescent organic material between the electrodes;

wherein the first electrode comprises a first material capable of injecting positive charge carriers into the light-emissive region and a second material capable of injecting negative charge carriers into the light-emissive region; and

the second electrode comprises a third material capable of injecting positive charge carriers into the light-emissive region and a fourth material capable of injecting negative charge carriers into the light-emissive region.

3. (Amended) An electroluminescent device as claimed in claim 1, wherein the second electrode has a surface facing the region of electroluminescent material and the third material and the fourth material are present at that surface.

4. (Amended) An electroluminescent device as claimed in claim 1, wherein the first electrode is formed by co-depositing the first and second materials.

5. (Amended) An electroluminescent device as claimed in claim 1, wherein the second electrode is formed by co-depositing the third and fourth materials.

6. (Amended) An electroluminescent device as claimed in claim 1, wherein at least one of the first and second electrodes is light-transmissive.

7. (Amended) An electroluminescent device as claimed in claim 1, wherein at least one of the first and third materials is gold or platinum.

8. (Amended) An electroluminescent device as claimed in claim 1, wherein at least one of the second and fourth materials is an alkali metal or an alkali earth metal or an oxide or fluoride of an alkali metal or an alkali earth metal.

9. (Amended) An electroluminescent material as claimed in claim 1, wherein at least one of the first and third materials has a work function above 4.0eV.

10. (Amended) An electroluminescent material as claimed in claim 1, wherein at least one of the second and fourth materials has a work function below 3.5eV.

11. (Amended) An electroluminescent device as claimed in claim 1, wherein the first and third materials are the same.

12. (Amended) An electroluminescent device as claimed in claim 1, wherein the second and fourth materials are the same.

13. (Amended) An electroluminescent device as claimed in claim 1, comprising a drive unit electrically connected to the first and second electrodes for applying an alternating current drive scheme to the electrodes.

14. (Amended) An electroluminescent device as claimed in claim 1, comprising a charge transport layer of an electrically conductive material between at least one of the electrodes and the light-emissive region.

Please cancel claim 15, without prejudice.

16. (Amended) A method of driving an electroluminescent device as claimed in claim 1, comprising applying an alternating current scheme to the electrodes.

Please cancel claim 17, without prejudice.

Please add new claim 18 as follows:

18. An electroluminescent device as claimed in claim 2, wherein the second electrode has a surface facing the region of electroluminescent material and the third material and the fourth material are present at that surface.

REMARKS

By the foregoing amendments to the specification, a cross-reference to the parent international application has been provided. The claims have been amended to better conform to U.S. practice and to omit multiple dependencies.

The filing fee has been calculated based on the claims as amended above. No new matter has been added.

Respectfully submitted,

MARSHALL, GERSTEIN & BORUN

December 3, 2001

By ______________________

James P. Zeller
Reg. No. 28,491

6300 Sears Tower
233 South Wacker Drive
Chicago, Illinois 60606-6402
(312) 474-6300

VERSION WITH MARKINGS TO SHOW CHANGES MADE

IN THE SPECIFICATION:

Page 1 immediately following the title, please insert the following:

--This is the U.S. national phase of International Application No. PCT/GB00/02121 filed June 1, 2000, the entire disclosure of which is incorporated herein by reference.--

Please amend claims 1, 3-14, and 16 as follows:

1. (Amended) An electroluminescent device comprising:

a first electrode;

a second electrode; and

a light-emissive region of electroluminescent organic material between the electrodes;

[and] wherein the first electrode comprises a first material capable of injecting positive charge carriers into the light-emissive region and a second material capable of injecting negative charge carriers into the light-emissive region; and

the second electrode comprises a third material capable of injecting positive charge carriers into the light-emissive region and a fourth material capable of injecting negative charge carriers into the light-emissive region.

3. (Amended) An electroluminescent device as claimed in claim 1 [or 2], wherein the second electrode has a surface facing the region of electroluminescent material and the third material and the fourth material are present at that surface.

4. (Amended) An electroluminescent device as claimed in [any preceding] claim 1, wherein the first electrode is formed by [co-deposition of] co-depositing the first and second materials.

5. (Amended) An electroluminescent device as claimed in [any preceding] claim 1, wherein the second electrode is formed by [co-deposition of] co-depositing the third and fourth materials.

6. (Amended) An electroluminescent device as claimed in [any preceding] claim 1, wherein at least one of the first and second electrodes is light-transmissive.

7. (Amended) An electroluminescent device as claimed in [any preceding] claim 1, wherein at least one of the first [and/or] and third [material] materials is gold or platinum.

8. (Amended) An electroluminescent device as claimed in [any preceding] claim 1, wherein at least one of the second [and/or] and fourth [material] materials is an alkali metal or [and] an alkali earth metal or an oxide or fluoride of an alkali metal or an alkali earth metal.

9. (Amended) An electroluminescent material as claimed in [any preceding] claim 1, wherein at least one [or both] of the first and third materials has a work function above 4.0eV.

10. (Amended) An electroluminescent material as claimed in [any preceding] claim 1, wherein at least one [or both] of the second and fourth materials has a work function below 3.5eV.

11. (Amended) An electroluminescent device as claimed in [any preceding] claim 1, wherein the first and third materials are the same.

12. (Amended) An electroluminescent device as claimed in [any preceding] claim 1, wherein the second and fourth materials are the same.

13. (Amended) An electroluminescent device as claimed in [any preceding] claim 1, comprising a drive unit electrically connected to the first and second electrodes for applying an alternating current drive scheme to the electrodes.

14. (Amended) An electroluminescent device as claimed in [any preceding] claim 1, comprising a charge transport layer of an electrically conductive material between at least one of the electrodes and the light-emissive region.

Please cancel claim 15, without prejudice.

16. (Amended) A method of driving an electroluminescent device as claimed in [any preceding] claim 1, comprising applying an alternating current scheme to the electrodes.

Please cancel claim 17, without prejudice.

Please add new claim 18 as follows:

18. An electroluminescent device as claimed in claim 2, wherein the second electrode has a surface facing the region of electroluminescent material and the third material and the fourth material are present at that surface.

ABSTRACT

A method for forming a patterned layer of a light-emissive material on a substrate, comprising the steps of providing a holed layer on the surface of the substrate, the holed layer being permanently attached to the substrate and defining a plurality of holes through which the underlying substrate is exposed, and applying a light-emissive material to the surface of the holed layer opposite the substrate and displacing the light-emissive material in fluid form across the surface of the holed layer so as to selectively deposit the material only in the holes of the holed layer.

LIGHT-EMITTING DEVICES

This invention relates to light-emitting devices, for example devices suitable as display devices.

One specific class of display devices is those that use an organic material for light emission. Light-emitting organic materials are described in PCT/WO90/13148 and US 4,539,507, the contents of both of which are incorporated herein by reference. The basic structure of these devices is a light-emitting organic layer, for instance a film of a poly(p-phenylenevinylene ("PPV"), sandwiched between two electrodes. One of the electrodes (the cathode) injects negative charge carriers (electrons) and the other electrode (the anode) injects positive charge carriers (holes). The electrons and holes combine in the organic layer generating photons. In PCT/WO90/13148 the organic light-emitting material is a polymer. In US 4,539,507 the organic light-emitting material is of the class known as small molecule materials, such as (8-hydroxyquinoline)aluminium ("Alq3"). In a practical device one of the electrodes is typically transparent, to allow the photons to escape the device.

Figure 1 shows the typical cross-sectional structure of an organic light-emitting device ("OLED"). The OLED is typically fabricated on a glass or plastic substrate 1 coated with a transparent anode electrode 2 of a material such as indium-tin-oxide ("ITO") that is suitable for injecting positive charge carriers. Such coated substrates are commercially available. This ITO-coated substrate is covered with at least a layer of a thin film of an electroluminescent organic material 3 and a final layer forming a cathode electrode 4 of a material that is suitable for injecting negative charge carriers. The cathode electrode is typically of a metal or alloy. Other layers can be included in the device, for example to improve charge transport between the electrodes and the electroluminescent material.

Figure 2 shows the energy levels of the layers in the device of figure 1. Under forward bias it is feasible for holes to pass from the anode electrode 2 and for

electrons to pass from the cathode electrode 4 into the emitting layer, where they can combine. Under reverse bias it is not favourable for electrons to pass from the electrode 2 into the emitting layer, or for holes to pass from the electrode 4 into the emitting layer 2. The device thus behaves as a diode.

Important measures of the performance of OLEDs are lifetime, power efficiency and turn-on voltage. It has been recognised that the lifetime of a typical OLED can often be extended by driving it intermittently or even by applying temporary reverse voltages between the anode and cathode electrodes (AC driving). However, since no light is emitted when there a negative applied voltage an AC drive scheme reduces light output from the OLED unless the device is driven harder during the times when it is under forward bias. This harder driving can accelerate degradation of the device. In some circumstances this can significantly offset any gains in lifetime from intermittent or AC driving.

According to the present invention there is provided an electroluminescent device comprising: a first electrode; a second electrode; and a light-emissive region of electroluminescent organic material between the electrodes; and wherein the first electrode comprises a first material capable of injecting positive charge carriers into the light-emissive region and a second material capable of injecting negative charge carriers into the light-emissive region; and the second electrode comprises a third material capable of injecting positive charge carriers into the light-emissive region and a fourth material capable of injecting negative charge carriers into the light-emissive region.

Preferably the device is capable of emitting light from the light-emissive region when the said negative charge carriers are injected from the first electrode and positive charge carriers are injected from the second electrode and is capable of emitting light from the light-emissive region when the said positive charge carriers are injected from the first electrode and negative charge carriers are injected from the second electrode.

Preferably the first, second third and fourth materials are capable of injecting charge carriers as said above when a voltage of magnitude less than 20, 10 or 5V is applied between the electrodes. One or both of the first and third materials may have a work function above 4.0eV or 4.5eV. One or both of the second and fourth materials may have a work function below 3.5eV or 3.0eV.

The first electrode suitably has a surface facing the region of electroluminescent material at which the first material and the second material are present. Preferably regions of the first and second materials are located adjacent to the region of electroluminescent material. The second electrode suitably has a surface facing the region of electroluminescent material at which the third material and the fourth material are present. Preferably regions of the third and fourth materials are located adjacent to the region of electroluminescent material.

The first and/or third material may, for example, be gold or platinum or ITO. The first and third materials may be the same or different. The second and/or fourth material may, for example, be an alkali metal or and alkali earth metal or an oxide or fluoride of an alkali metal or an alkali earth metal, suitably having a low work function - for example below 3.5eV. The second and/or fourth material may be a fluoride or oxide of a low work function metal such as Li, Ca, Mg, Cs, Ba, Yb, Sm etc. The second and/or fourth materials may be the same or different.

Preferably either or both of the electrodes may be light-transmissive, most preferably transparent.

According to a second aspect of the present invention there is provided a method of driving an electroluminescent device as described above, comprising applying an alternating current drive scheme to the electrodes. The alternating current drive scheme may comprise repeatedly biasing the first electrode positively relative to the second electrode and subsequently biasing the first electrode negatively relative to the second electrode. The scheme may or may not be

periodic. The scheme may or may not include periods when neither electrode is biased relative to the other.

Where the device is driven by a scheme that includes periods of opposite biasing it is preferred that the voltage applied across the electrodes when the first electrode is biased positively relative to the second electrode is such as to cause electron/hole recombination in a different zone of the light-emissive region than does the voltage applied across the electrodes when the first electrode is biased negatively relative to the second electrode.

The light-emitting material is suitably an organic material and preferably a polymer material. The light-emitting material is preferably a semiconductive and/or conjugated polymer material. Alternatively the light-emitting material could be of other types, for example sublimed small molecule films or inorganic light-emitting material. The or each organic light-emitting material may comprise one or more individual organic materials, suitably polymers, preferably fully or partially conjugated polymers. Example materials include one or more of the following in any combination: poly(p-phenylenevinylene) ("PPV"), poly(2-methoxy-5(2'-ethyl)hexyloxyphenylenevinylene) ("MEH-PPV"), one or more PPV-derivatives (e.g. di-alkoxy or di-alkyl derivatives), polyfluorenes and/or co-polymers incorporating polyfluorene segments, PPVs and related co-polymers, poly(2,7-(9,9-di-n-octylfluorene)-(1,4-phenylene-((4-secbutylphenyl)imino)-1,4-phenylene)) ("TFB"), poly(2,7-(9,9-di-n-octylfluorene) - (1,4-phenylene-((4-methylphenyl)imino)-1,4-phenylene-((4 - methylphenyl)imino) - 1,4-phenylene)) ("PFM"), poly(2,7 - (9,9 - di-n-octylfluorene) - (1,4-phenylene-((4-methoxyphenyl)imino)-1,4-phenylene-((4-methoxyphenyl)imino)-1,4-phenylene)) ("PFMO"), poly (2,7-(9,9-di-n-octylfluorene) ("F8") or (2,7-(9,9-di-n-octylfluorene)-3,6-Benzothiadiazole) ("F8BT"). Alternative materials include small molecule materials such as Alq3. The light-emitting region may include two or more such materials.

One or more charge-transport layers may be provided between the light-emitting region and one or both of the electrodes, or integrated into the light-emitting

region. The or each charge transport layer may suitably comprise one or more polymers such as polystyrene sulphonic acid doped polyethylene dioxythiophene ("PEDOT-PSS"), poly(2,7-(9,9-di-n-octylfluorene)-(1,4-phenylene-(4-imino(benzoic acid))-1,4-phenylene-(4-imino(benzoic acid))-1,4-phenylene)) ("BFA"), polyaniline and PPV.

The present invention will now be described by way of example with reference to the accompanying drawings, in which:

figure 3 is a cross-section of a light-emitting device; and

figures 4 and 5 illustrate drive schemes.

The device of figure 3 comprises a region 10 of light-emissive material located between two electrode structures 11 and 12. The electrode structures are connected to a drive unit 13 which is capable of applying a voltage between the electrode structures. The electrode structures are formed so as to be capable of allowing relatively efficient emission from the light-emissive material whether electrode structure 11 is the anode (and therefore electrically positive relative to electrode structure 12) or the cathode (and therefore electrically negative relative to electrode structure 12).

The device of figure 3 is formed on a glass substrate 14 which is coated with a contact layer 15 of indium-tin oxide (ITO). Such ITO-coated glass substrates are commercially available. The glass sheet could be a sheet of sodalime or borosilicate glass of a thickness of, for instance, 1mm. Instead of glass other materials such as Perspex could be used. The thickness of the ITO coating is suitably around 150nm and the ITO suitably has a sheet resistance of between 10 and 30Ω/□, preferably around 15Ω/□.

Over the ITO layer 15 is deposited a charge injection layer 16 of Au and LiF. This layer could be formed by co-evaporation of the Au and LiF. The thickness of layer 15 is suitably between 2 and 20nm, preferably around 5nm. A suitable Au:LiF ratio - for example 1:1 - is selected. The microstructure of the Au:LiF layer is

selected to achieve the desired bi-directional device performance (for which the high and low work-function components should preferably exhibit their bulk properties at the interfaces with the emissive material) together with adequately uniform emission at the expected viewing distance of the device. A device that is intended to be viewed from short range may need the electrodes to have a finer microstructure than can be tolerated in one that is intended to be viewed from long range.

Then light-emissive material is deposited to form region 10. The light-emissive material could be any suitable light-emissive polymer, small molecule or oligomer material or the like, or a mixture of two or more of such materials together optionally with other materials. The layer could be formed by substituted poly(p-phenylenevinylene) polymers. This is deposited on top of layer 2 by spin-coating from an organic solvent. The light-emissive material may be mixed with components that assist charge transport within the light-emissive region. The thickness of the layer of light-emissive material is suitably around 90nm.

The electrode 12 comprises a second charge injection layer 17 of Au and LiF, which could again be deposited by co-evaporation of those components. The thickness of the layer 17 is suitably around 20nm.

Over the charge injection layer 17 is a second contact layer 18 of Al, which could be deposited by evaporation. The thickness of the layer 18 is suitably around 500nm.

After the layer 18 has been deposited the contacts are made to the layers 15 and 18 and the device is encapsulated in epoxy-glass for environmental protection.

Electrode structure 11 comprises layers 15 and 16. Electrode structure 12 comprises layers 17 and 18.

Each of the charge injection layers 16 and 17 comprises a material of a relatively high work function (Au) and a material of a relatively low work function (LiF). The microstructure of the layers is such that those materials are present throughout the layers, and especially at the surface of each of the layers that is adjacent the light-emissive region. As a result of this the charge injection layers can operate to inject charge relatively efficiently whether they are the anode or the cathode of the device during use. The electrically conductive contact layers 15 and 18 act as an interface to the connectors to the drive unit 13 and help to distribute charge evenly over the charge injection layers. The charge injection layers 16 and 17 could include further high or low work function components and/or components to increase electrical conductivity through the layers.

In the embodiment of figure 3 the substrate 14, contact layer 15 and injection layer 16 are light-transmissive and preferably transparent so that light can leave the device through the substrate. (See arrow 19). In other devices the other electrode structure 12 could be light transmissive, or light could be emitted through the sides of the device.

Figure 4 shows examples of schemes that can be used to drive the device of figure 3. Figure 4 shows a series of schematic plots of applied voltage between the layers 15 and 17 against time.

Scheme A shows the application of a constant voltage whereby the layer 15 is maintained at a higher potential (positive) than layer 17. In this case the electrode structure 11 acts as the anode and the electrode structure 12 acts as the cathode. The electrode 11 injects holes into the light-emitting material by means of the high work function Au component of layer 16. The electrode 12 injects electrons into the light-emitting material by means of the low work function LiF component of layer 17.

Scheme B shows the application of a constant voltage whereby the layer 15 is maintained at a lower potential (negative) than layer 17. In this case the electrode

structure 11 acts as the cathode and the electrode structure 12 acts as the anode. The electrode 11 injects electrons into the light-emitting material by means of the low work function LiF component of layer 16. The electrode 12 injects holes into the light-emitting material by means of the high work function Au component of layer 17.

The device can thus operate relatively efficiently under forward and reverse bias (schemes A and B). It can also operate under alternating current (AC) drive schemes, examples of which are given in schemes C to G. It is believed that AC drive schemes may offer a number of advantages over direct current (DC) drive schemes. One reason for the failure of OLEDs is migration of components of the device towards one of the electrodes under an applied field of a constant direction. An AC scheme can address this problem by inducing migration in the opposite direction when a reverse field is applied. In addition, in some circumstances it may be more convenient for hardware reasons to drive an OLED by AC.

Scheme C is a simple square wave alternating current drive scheme in which the positive and negative sections of the scheme are of equal period and voltage.

Scheme D is a simple sine wave alternating current drive scheme in which the positive and negative sections of the scheme are of equal period and voltage.

The scheme need not be symmetrical. Scheme E is a square wave scheme in which the positive and negative sections of the scheme are of different levels. This scheme may be useful if the device emits more efficiently under on bias than under the other since the brightness of the device may then be maintained constant by means of this scheme. Scheme F is a square wave scheme in which the positive and negative sections of the scheme are of different durations. This scheme may be useful if migration is greater under one bias than under the other.

Scheme G in figure 4 includes periods of zero voltage.

The drive scheme need not be periodic: it could be random.

When a device as described above is driven by an AC drive scheme further improvements in lifetime may be achieved by an additional mechanism. It is believed that in a conventional device degradation of the light-emissive material is greatest in the region of the material where electron/hole recombination occurs. This is in a fixed zone of the material for a given brightness. When the device of figure 3 is operated in reverse recombination is likely to occur in a different zone. Therefore, in the device of figure 3 degradation can be distributed more evenly throughout the light-emissive region. Figure 5 shows a generalised periodic square wave drive scheme. By varying V_P, V_N, t_P and t_N the scheme can result in a desired brightness, with the recombination/degradation zones in different locations.

One of the materials of each charge injecting layer suitably has a work function that is close to the LUMO level of the light-emitting material. One of the materials of each charge injecting layer suitably has a work function that is close to the HOMO level of the light-emitting material. For typical organic light-emissive materials it is preferred that one of the materials of each charge injection layer has a work function that is greater than 4.0, 4.1, 4.2, 4.3, 4.4 or 4.5eV or is higher than 4.5eV, and/or that another of the materials of each charge injection layer has a work function that is less than 3.5, 3.4, 3.3, 3.2, 3.1 or 3.0eV or is lower than 3.0eV. The charge injection layers may have the same or different compositions.

There may be one or more charge transport layers between either or both of the electrodes and the emissive layer. The charge transport layers may be of an electrically conductive organic material such as polystyrene sulphonic acid doped polyethylene dioxythiophene ("PEDOT-PSS").

The device could form part of a larger display unit having a number of independently controllable display elements or pixels. The pixels could be of the

same or different shapes. The pixels could be addressed by any suitable addressing schemes, including active and passive matrix addressing.

The applicant draws attention to the fact that the present invention may include any feature or combination of features disclosed herein either implicitly or explicitly or any generalisation thereof, without limitation to the scope of any of the present claims. In view of the foregoing description it will be evident to a person skilled in the art that various modifications may be made within the scope of the invention.

CLAIMS

1. An electroluminescent device comprising:

a first electrode;

a second electrode; and

a light-emissive region of electroluminescent organic material between the electrodes;

and wherein

the first electrode comprises a first material capable of injecting positive charge carriers into the light-emissive region and a second material capable of injecting negative charge carriers into the light-emissive region; and

the second electrode comprises a third material capable of injecting positive charge carriers into the light-emissive region and a fourth material capable of injecting negative charge carriers into the light-emissive region.

2. An electroluminescent device as claimed in claim 1, wherein the first electrode has a surface facing the region of electroluminescent material and the first material and the second material are present at that surface.

3. An electroluminescent device as claimed in claim 1 or 2, wherein the second electrode has a surface facing the region of electroluminescent material and the third material and the fourth material are present at that surface.

4. An electroluminescent device as claimed in any preceding claim, wherein the first electrode is formed by co-deposition of the first and second materials.

5. An electroluminescent device as claimed in any preceding claim, wherein the second electrode is formed by co-deposition of the third and fourth materials.

6. An electroluminescent device as claimed in any preceding claim, wherein at least one of the first and second electrodes is light-transmissive.

7. An electroluminescent device as claimed in any preceding claim wherein the first and/or third material is gold or platinum.

8. An electroluminescent device as claimed in any preceding claim wherein the second and/or fourth material is an alkali metal or and alkali earth metal or an oxide or fluoride of an alkali metal or an alkali earth metal.

9. An electroluminescent material as claimed in any preceding claim, wherein one or both of the first and third materials has a work function above 4.0eV.

10. An electroluminescent material as claimed in any preceding claim, wherein one or both of the second and fourth materials has a work function below 3.5eV.

11. An electroluminescent device as claimed in any preceding claim, wherein the first and third materials are the same.

12. An electroluminescent device as claimed in any preceding claim, wherein the second and fourth materials are the same.

13. An electroluminescent device as claimed in any preceding claim, comprising a drive unit electrically connected to the first and second electrodes for applying an alternating current drive scheme to the electrodes.

14. An electroluminescent device as claimed in any preceding claim, comprising a charge transport layer of an electrically conductive material between at least one of the electrodes and the light-emissive region.

15. An electroluminescent device substantially as herein described with reference to figures 3 to 5 of the accompanying drawings.

16. A method of driving an electroluminescent device as claimed in any preceding claim, comprising applying an alternating current drive scheme to the electrodes.

17. An electroluminescent device substantially as herein described with reference to figures 3 to 5 of the accompanying drawings.

1/3

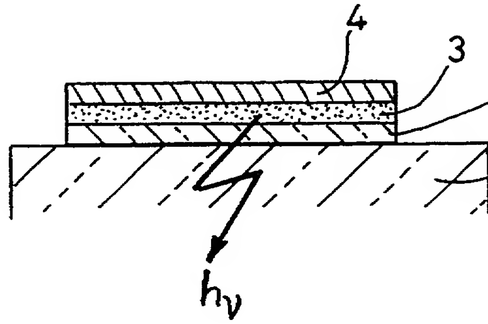

Fig. 1

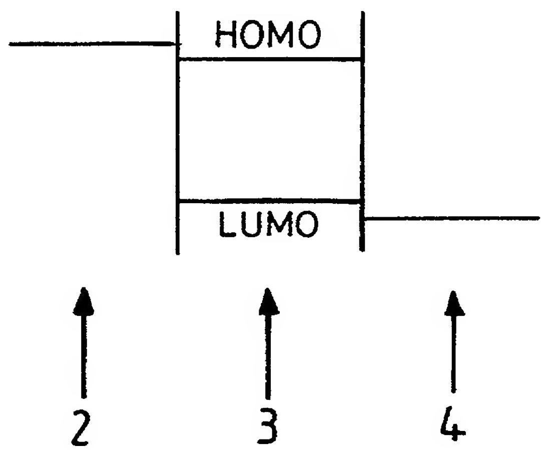

Fig. 2

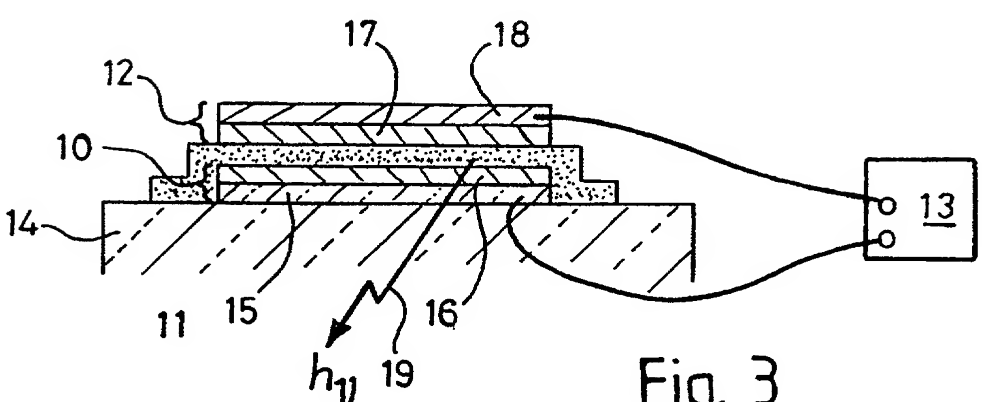

Fig. 3

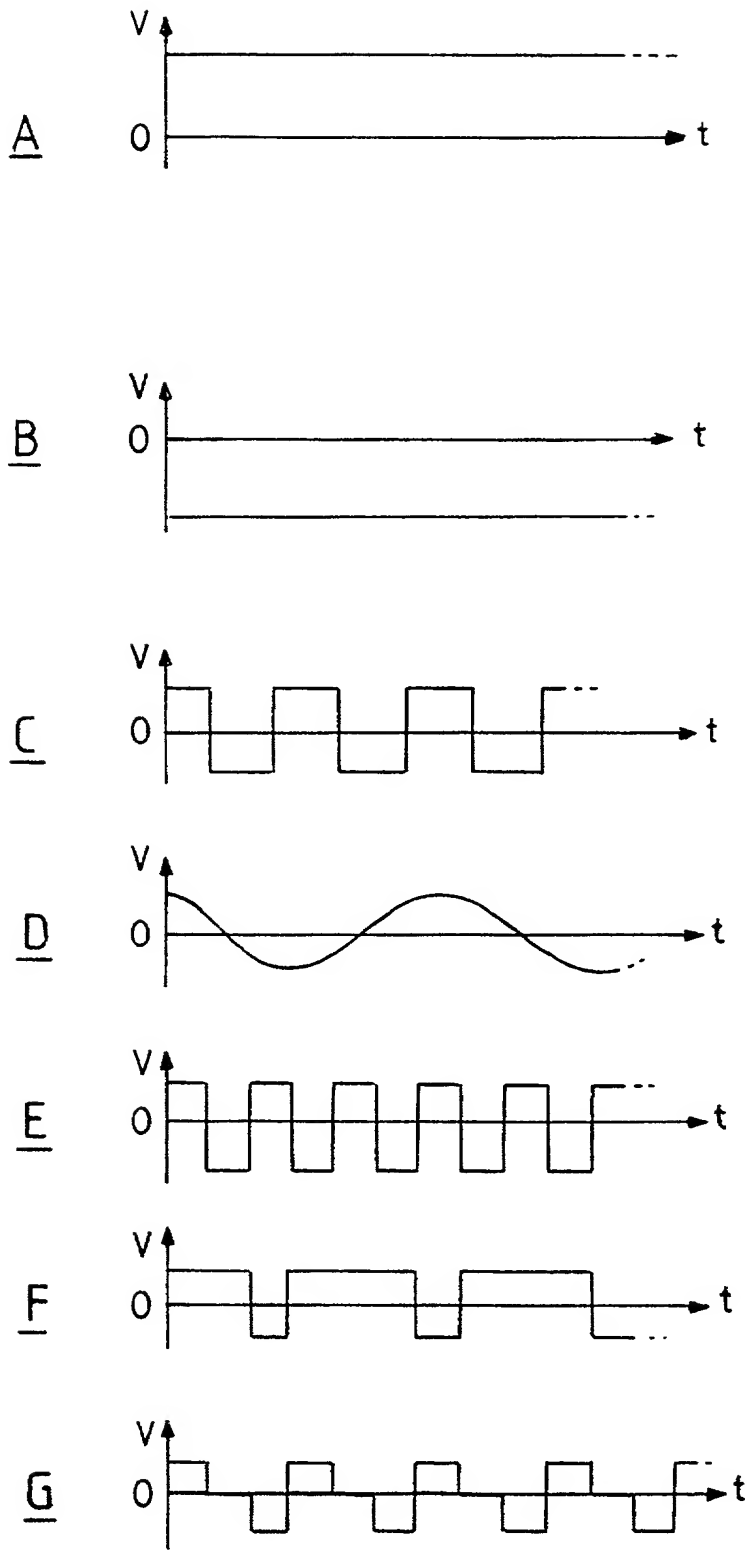

Fig. 4

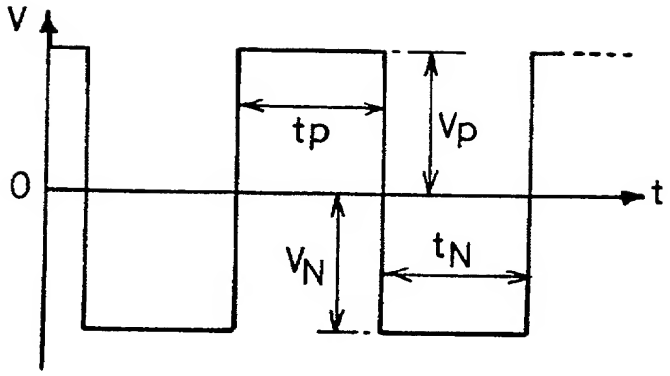

Fig. 5

APPLICABLE RULES AND STATUTES

37 CFR 1.56. DUTY OF DISCLOSURE - INFORMATION MATERIAL TO PATENTABILITY (Applicable Portion)

(a) A patent by its very nature is affected with a public interest. The public interest is best served, and the most effective patent examination occurs when, at the time an application is being examined, the Office is aware of and evaluates the teachings of all information material to patentability. Each individual associated with the filing and prosecution of a patent application has a duty of candor and good faith in dealing with the Office, which includes a duty to disclose to the Office all information known to that individual to be material to patentability as defined in this section. The duty to disclose information exists with respect to each pending claim until the claim is canceled or withdrawn from consideration, or the application becomes abandoned. Information material to the patentability of a claim that is canceled or withdrawn from consideration need not be submitted if the information is not material to the patentability of any claim remaining under consideration in the application. There is no duty to submit information which is not material to the patentability of any existing claim. The duty to disclose all information known to be material to patentability is deemed to be satisfied if all information known to be material to patentability of any claim issued in a patent was cited by the Office or submitted to the Office in the manner prescribed by §§ 1.97(b)-(d) and 1.98. However, no patent will be granted on an application in connection with which fraud on the Office was practiced or attempted or the duty of disclosure was violated through bad faith or intentional misconduct. The Office encourages applicants to carefully examine:

(1) prior art cited in search reports of a foreign patent office in a counterpart application, and
(2) the closest information over which individuals associated with the filing or prosecution of a patent application believe any pending claim patentability defines, to make sure that any material information contained therein is disclosed to the Office.

Information relating to the following factual situations enumerated in 35 USC 102 and 103 may be considered material under 37 CFR 1.56(a).

35 U.S.C. 102. CONDITIONS FOR PATENTABILITY: NOVELTY AND LOSS OF RIGHT TO PATENT

A person shall be entitled to a patent unless --

(a) the invention was known or used by others in this country, or patented or described in a printed publication in this or a foreign country, before the invention thereof by the applicant for patent, or

(b) the invention was patented or described in a printed publication in this or a foreign country or in public use or on sale in this country, more than one year prior to the date of the application for patent in the United States, or

(c) he has abandoned the invention, or

(d) the invention was first patented or caused to be patented, or was the subject of an inventor's certificate, by the applicant or his legal representatives or assigns in a foreign country prior to the date of the application for patent in this country on an application for patent or inventor's certificate filed more than twelve months before the filing of the application in the United States, or

(e) the invention was described in a patent granted on an application for patent by another filed in the United States before the invention thereof by the applicant for patent, or on an international application by another who has fulfilled the requirements of paragraph (1), (2), and (4) of section 371(c) of this title before the invention thereof by the applicant for patent, or

(f) he did not himself invent the subject matter sought to be patented, or

(g) before the applicant's invention thereof the invention was made in this country by another who had not abandoned, suppressed, or concealed it. In determining priority of invention there shall be considered not only the respective dates of conception and reduction to practice of the invention, but also the reasonable diligence of one who was first to conceive and last to reduce to practice, from a time prior to conception by the other.

35 U.S.C. 103. CONDITIONS FOR PATENTABILITY; NON-OBVIOUS SUBJECT MATTER (Applicable Portion)

A patent may not be obtained though the invention is not identically disclosed or described as set forth in section 102 of this title, if the differences between the subject matter sought to be patented and the prior art are such that the subject matter as a whole would have been obvious at the time the invention was made to a person having ordinary skill in the art to which said subject matter pertains. Patentability shall not be negatived by the manner in which the invention was made.

Subject matter developed by another person, which qualifies as prior art only under subsection (f) or (g) of section 102 of this title, shall not preclude patentability under this section where the subject matter and the claimed invention were, at the time the invention was made, owned by the same person or subject to an obligation of assignment to the same person.

35 U.S.C. 112. SPECIFICATION (Applicable Portion)

The specification shall contain a written description of the invention, and of the manner and process of making and using it, in such full, clear, concise, and exact terms as to enable any person skilled in the art to which it pertains, or with which it is most nearly connected, to make and use the same, and shall set forth the best mode contemplated by the inventor of carrying out his invention.

DECLARATION FOR PATENT APPLICATION AND POWER OF ATTORNEY

As a below named inventor, I hereby declare that my residence, post office address and citizenship are as stated below next to my name; I believe that I am an original, first and joint inventor of the subject matter which is claimed and for which a patent is sought on the invention entitled "**LIGHT-EMITTING DEVICES,**" the specification of which was filed on June 1, 2000, as Application Serial No. 10/009,079 and was amended on December 3, 2001. I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment(s) referred to above. I acknowledge the duty to disclose to the Patent and Trademark Office all information known to me to be material to patentability as defined in 37 C.F.R. §1.56.

I hereby claim foreign priority benefits under 35 U.S.C. §119 of any foreign application(s) for patent or inventor's certificate or of any PCT international application(s) designating at least one country other than the United States of America listed below and have also identified below any foreign application(s) for patent or inventor's certificate or any PCT international application(s) designating at least one country other than the United States of America filed by me on the same subject matter having a filing date before that of the application(s) of which priority is claimed:

			Priority Claimed	
9913449.6	Great Britain	09 June 1999	☒	☐
(Application Serial Number)	(Country)	(Day/Month/Year Filed)	Yes	No

I hereby claim the benefit under 35 U.S.C. §119(e) of any United States provisional application(s) listed below:

(Application Serial Number)	(Day/Month/Year Filed)

I hereby claim the benefit under 35 U.S.C. §120 of any United States application(s) or PCT international application(s) designating the United States of America listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior application(s) in the manner provided by the first paragraph of 35 U.S.C. §112, I acknowledge the duty to disclose to the Office all information known to me to be material to patentability as defined in 37 C.F.R. §1.56 which occurred between the filing date of the prior application(s) and the national or PCT international filing date of this application:

PCT/GB00/02121	01 June 2000	Pending
(Application Serial Number)	(Day/Month/Year Filed)	(Status-Patented, Pending or Abandoned)

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under 18 U.S.C. §1001 and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

POWER OF ATTORNEY: I hereby appoint as my attorneys, with full powers of substitution and revocation, to prosecute this application and transact all business in the Patent and Trademark Office connected therewith:

John B. Lungmus(18,566)	Patrick D. Ertel (26,877)	James J. Napoli (32,361)	Roger A. Heppermann (37,641)
Allen H. Gerstein (22,218)	Richard B. Hoffman(26,910)	Richard M. La Barge (32,254)	David A. Gass (38,153)
Nate F. Scarpelli (22,320)	James P. Zeller (28,491)	Robert M. Gerstein (34,824)	Gregory C. Mayer (38,238)
Michael F. Borun (25,447)	Kevin D. Hogg (31,839)	Anthony G. Sitko (36,278)	Michael R. Weiner (38,359)
Carl E. Moore, Jr. (26,487)	Jeffrey S. Sharp (31,879)	James A. Flight (37,622)	William K. Merkel (40,725)
Richard H. Anderson (26,526)	Martin J. Hirsch (32,237)		Andrew M. Lawrence (46,130)

(23)

Send correspondence to: James P. Zeller

FIRM NAME	PHONE NO.	STREET	CITY & STATE	ZIP CODE
Marshall, Gerstein & Borun	312-474-6300	6300 Sears Tower 233 South Wacker Drive	Chicago, Illinois	60606-6357

1-00

Full Name of First or Sole Inventor Julian Carter	Citizenship United Kingdom
Residence Address - Street 6 High Street	Post Office Address - Street 6 High Street
City (Zip) Dry Drayton, Cambridgeshire CB3 8BS GBX	City (Zip) Dry Drayton, Cambridgeshire CB3 8BS
State or Country United Kingdom	State or Country United Kingdom
Date ☒ 8/4/02	Signature ☒ J.Clark

2-00

Second Joint Inventor, if any Stephen Karl Heeks,	Citizenship United Kingdom
Residence Address - Street 127 Rampton Road	Post Office Address - Street 127 Rampton Road
City (Zip) Cottenham, Cambridgeshire CB4 8TJ GBX	City (Zip) Cottenham, Cambridgeshire CB4 8TJ
State or Country United Kingdom	State or Country United Kingdom
Date ☒ 27/3/02	Signature ☒ S.Heeks